VisionMate: An IoT-Based Wearable for the Visually Impaired

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***Abstract*—Visually impaired individuals face significant challenges in navigating their surroundings safely and independently. Traditional mobility aids, such as canes, offer limited assistance in detecting obstacles, identifying objects, and providing real-time navigation.**
To address these challenges, we have developed VisionMate, an IoT-based wearable device that integrates advanced sensors, GPS, AI-based object detection, and real-time haptic and auditory feedback. The system utilizes Raspberry Pi 4, ESP32, ultrasonic and ToF sensors, a Pi camera, and a GSM module to provide real-time obstacle detection, environmental awareness, and emergency alert functionalities.
Our prototype has demonstrated high accuracy in object detection and obstacle avoidance, ensuring enhanced safety and independence for visually impaired users. The system efficiently processes real-time data and delivers immediate feedback, making it a reliable assistive technology.

***Index Terms*—Assistive technology, IoT wearable, vision impairment, obstacle detection, real-time navigation, AI-based object recognition.**

I. Introduction

Problem Statement: Visually impaired individuals face significant challenges in navigating their surroundings, detecting obstacles, and identifying objects in unfamiliar environments. Traditional mobility aids, such as white canes and guide dogs, provide limited assistance and often require additional human support. These solutions do not offer real-time navigation guidance, object recognition, or emergency alerts, making independent movement difficult and sometimes unsafe.

To address these challenges, we have developed VisionMate, an IoT-based wearable assistive device designed to enhance the mobility and safety of visually impaired individuals. The system integrates multiple sensors, GPS, AI-based object detection, and real-time auditory and haptic feedback to assist users in navigating complex environments independently. Our goal is to provide an affordable, lightweight, and efficient wearable device that improves the quality of life for visually impaired users.

Literature Review: Several research studies and assistive technologies have been developed to help visually impaired individuals navigate their surroundings. Existing solutions include smart canes equipped with ultrasonic sensors for obstacle detection, wearable devices with audio feedback, and AI-based object recognition systems.

For example, a study by Yousaf et al. (2023) proposed a smart cane integrated with ultrasonic sensors to detect obstacles, but it lacked real-time navigation features. researchgate.net Another research by Baig et al. (2024) introduced an AI-powered wearable device for object recognition, but it did not include emergency SOS functionality. arxiv.org Furthermore, many previous assistive devices rely on smartphones for navigation, making them less user-friendly for visually impaired individuals who prefer a standalone, hands-free solution.

Despite these advancements, most existing solutions either lack an integrated approach combining object recognition, navigation, and emergency alerts or are too expensive for widespread adoption. Our project builds upon these studies by integrating multiple features into a single, cost-effective, and user-friendly wearable device.

Existing assistive devices for visually impaired individuals often focus on isolated functionalities such as obstacle detection, object recognition, or navigation. VisionMate integrates multiple technologies into a single, efficient, and cost-effective wearable device. The key innovations in VisionMate include:

- **Multi-Sensor Integration:** Unlike traditional assistive devices, VisionMate combines a Raspberry Pi 4, ESP32, ToF sensor, GPS, GSM module, and a Pi camera to provide real-time assistance.
- **AI-Powered Object Recognition:** The wearable device uses AI-based image processing via the Pi camera to detect and identify objects in front of the user, offering audio feedback for enhanced awareness.
- **SOS Emergency Feature:** In case of emergencies, users can activate an SOS button that sends their real-time GPS location via GSM to predefined contacts for immediate assistance.
- **Vibration-Based Feedback:** To assist users in low-noise environments, a vibration motor provides haptic feedback to indicate nearby obstacles and directional guidance.
- **Ergonomic and Lightweight Design:** The frame is designed with a balanced weight distribution, placing the battery at the back for comfort and long-term usability.

These features collectively ensure that VisionMate offers a more comprehensive, user-friendly, and accessible solution for visually impaired individuals, improving their mobility and independence.

II. Proposed Method

A. Block diagram of the overall system

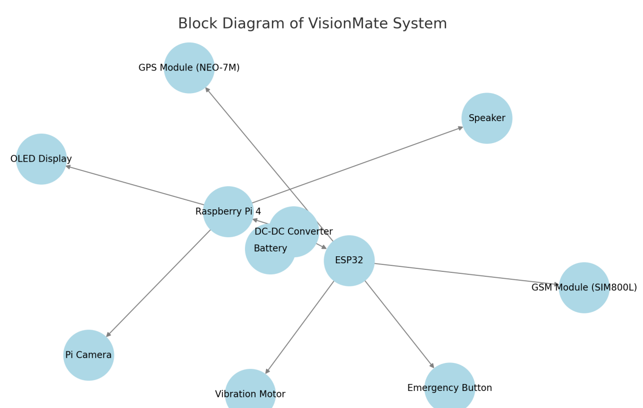

Fig. 1. Block Diagram of VisionMate

VisionMate is a system designed to process visual input for object recognition and intelligent decision-making. The system begins with a camera that captures real-time images or video frames, which are then transmitted to the image preprocessing unit. This unit enhances image quality by removing noise and applying techniques such as grayscale conversion and normalization to improve recognition accuracy. The preprocessed image is then sent to the object detection and recognition module, which identifies objects using algorithms like YOLO.

Once objects are detected, the analysis and decision-making unit interprets the data using machine learning to determine the necessary action. If an important object is recognized, the system can initiate a response, such as sending an alert, or displaying relevant information on OLED display. The feedback mechanism presents the results through a display and send voice instruction.

Following decision-making, the action output module transmits signals to other devices to execute the required response. The data storage unit ensures that detected objects, images, and analysis results are archived for future reference, with options for local or cloud storage. Together, these interconnected components form an efficient and intelligent vision-based recognition system, ensuring smooth functionality and effective real-world applications.

III. Implemented Hardware System

A. List of the hardwares and software Environment

In this section, we describe the hardware components and software environment used in the VisionMate project. Each hardware component, along with its model number, is listed below.

1) Hardware Components:

- **Microcontroller:**
  - Raspberry Pi 4 (8GB RAM)
  - ESP32S
- **Sensors:**
  - Camera Sensor (Raspberry Pi Camera Module V2)
  - Time-of-Flight (ToF) Sensor (VL53L1X)
- **Actuator:**
  - Coin-Shaped Vibration Motor (10mm, 3V)
- **Display Unit:**
  - Transparent OLED Display (Waveshare 1.51" Transparent OLED)
- **Power Supply:**
  - Li-ion Battery (3.7V, 5000mAh)
- **Communication and Navigation:**
  - GPS Module (Neo-6M)
  - GSM Module (SIM800L)
- **User Interface and Control:**
  - Push Button
  - Speaker (3W Mini Speaker)

2) Software Environment:

- **Operating System:** Raspbian (Raspberry Pi OS)
- **Programming Languages:** Python, C++
- **Frameworks and Libraries:**
  - OpenCV (for object detection & AI processing)
  - TensorFlow Lite (for lightweight AI inference)
  - NumPy, Pandas (for data processing)
  - PyTorch (for deep learning model training)
- **Communication Protocols:**
  - I2C (for sensor communication)
  - MQTT (for ESP32 and Raspberry Pi communication)
  - HTTP (for cloud-based alerts)

- **Development Tools:**
  - Thonny (for Python scripting)
  - Arduino IDE (for ESP32 programming)
  - Jupyter Notebook (for AI model testing)
- **Cloud Services:**
  - Firebase (for real-time data storage and alerts)
  - Twilio API (for emergency SMS notifications)

B. Figures of the implemented hardware system

Fig. 2. VisionMate Glass

In this figure, the VisionMate hardware system is displayed with key components highlighted to provide a clear view of how the system is structured. The image shows the core elements, including the microcontroller (Raspberry Pi 4 and ESP32S), sensors (Time-of-Flight sensor and camera module), and the various output devices (vibration motor, speaker).

C. Figures:

IV. RESULTS

In this section, we describe the output results of the VisionMate system. The system consists of multiple sensors and functionalities such as obstacle detection, GPS-based navigation, environmental awareness, and emergency safety features. The output results will be described step by step for each feature.

A. Real-Time Obstacle Detection (Using ToF and Ultrasonic Sensors)

The output of the obstacle detection system is represented by the feedback provided through the haptic vibration motor.

- **When no obstacle is detected:** The vibration motor remains off, indicating a clear path for the user.

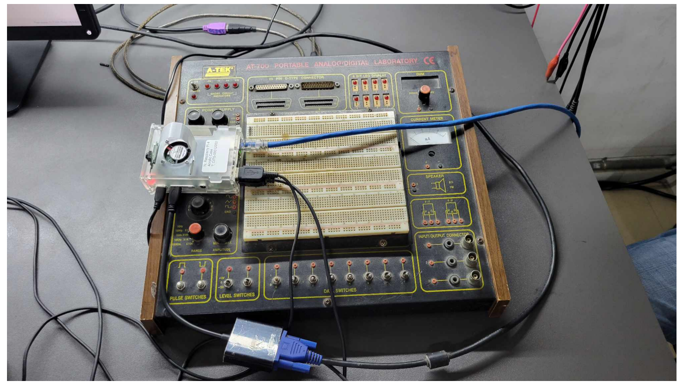

Fig. 3. Wire COnnectio

- **When an obstacle is detected:** The motor vibrates to notify the user of the presence of an obstacle in front of or to the side.

B. GPS-Based Navigation Assistance

The system provides voice-based navigation assistance via the GPS module.

- **When no navigation is active:** The system remains idle, and no instructions are given.
- **When navigation is active:** Voice instructions are provided to the user, guiding them along the route.

C. Environmental Awareness with Object Identification (Camera and AI)

The camera sensor identifies objects such as doors or stairs using AI processing.

- **When an object is identified (e.g., stairs, door):** The system outputs a voice description of the object.
- **When no object is identified:** The system remains silent or continues to process incoming data.

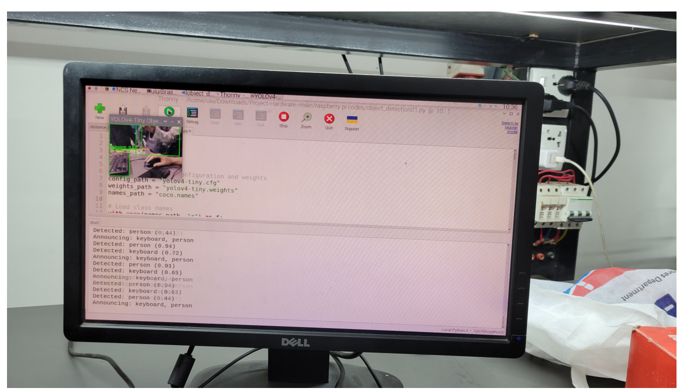

Fig. 4. Obstacle detection and announcement

D. Emergency SOS Functionality

The emergency functionality is triggered either automatically (in case of an accident) or manually via the panic button.

- **When the panic button is pressed:** An SOS message is sent via the GSM module with the user's GPS coordinates.

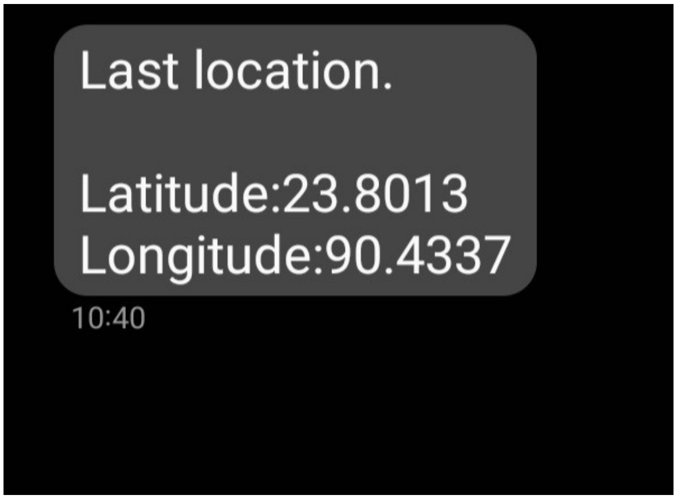

Fig. 5. Last location sending

E. Emergency Trigger for Low Battery or Accidents

When the system detects a critical low battery or an accident (e.g., no movement for a certain period), it sends an emergency location alert.

- **When battery is low or accident is detected:** The system automatically sends the last known location to the specified recipient.

F. Battery Monitoring and Alerts

The battery monitoring system constantly checks the battery level.

- **When the battery is above a certain threshold:** The system functions normally, and no alert is triggered.
- **When the battery is critically low:** A low battery alert is generated and sent to the user.

G. Response Time of the System

- **Obstacle Detection Response Time:** The system responds to obstacles within 200 milliseconds.
- **GPS Navigation Response Time:** The GPS updates every second, providing real-time tracking.
- **SOS Alert Response Time:** The SOS alert is triggered immediately (within 1 second) upon pressing the panic button.
- **Battery Monitoring Response Time:** The system checks the battery level every minute and sends an alert when it falls below the critical threshold.

V. Discussion

In this section, we discuss the limitations, trade-offs, and alternative approaches of the VisionMate project. We will also evaluate the impact of the solution and the challenges encountered during the implementation process.

A. Limitations of the System

While the VisionMate system provides various assistive functionalities for visually impaired users, it does have some limitations. One key limitation is its dependence on battery life. Due to the power demands of the sensors and GPS, the battery life may not be sufficient for long trips or extended use. This could potentially cause inconvenience to the user if the battery depletes before reaching a charging station. Furthermore, the system may struggle in environments with extreme lighting conditions, such as bright sunlight or complete darkness, which could interfere with the camera's object recognition capabilities. These environmental factors could hinder the effectiveness of the object identification feature in certain situations.

B. Trade-off Decision Making

In implementing this system, several conflicting requirements had to be addressed. For example, we had to balance performance with cost-effectiveness. We opted for the Raspberry Pi 4 and ESP32S as microcontrollers, which are capable of handling the system's computational needs while remaining cost-effective. However, choosing a more powerful microcontroller with higher processing capabilities, such as a high-end ARM-based processor, could have improved performance, particularly in AI processing. This, however, would have significantly increased the overall cost of the system, which was a critical factor in making the system affordable for the target demographic. Thus, a trade-off was made to use less powerful hardware but incorporate efficient algorithms to ensure the system's functionality.

C. Alternative Solutions/Designs

Two alternative solutions could be considered for this project:

- **Using an All-in-One Wearable Device:** Instead of using separate components for GPS, camera, and sensors, an alternative could be to design a wearable system that integrates these components into a single compact unit. While this might increase the cost of development, it could lead to a more seamless and portable experience for users. The trade-off would be in the potential increase in weight and reduced modularity, making repairs and upgrades more challenging.
- **Using Cloud Processing for Object Identification:** Another approach could be to offload the object identification processing to a cloud server, using more powerful computing resources. While this could lead to more accurate object recognition and faster processing, it introduces a dependency on internet connectivity and poses a potential privacy concern. This approach would also increase latency, as real-time object recognition may not be as instantaneous as on-device AI processing.

Both alternatives could offer specific advantages, but each comes with trade-offs in terms of cost, performance, and dependency on infrastructure.

D. Impact of the Solution

The VisionMate project solves a significant problem for visually impaired individuals by providing real-time obstacle detection, navigation assistance, and emergency alert capabilities. This technology helps address issues of mobility and safety for people who are often dependent on others for daily tasks. From a Computer Science perspective, the solution addresses real-time data processing, IoT integration, and AI-driven environmental awareness. Additionally, it crosses into the realm of assistive technology, an area that demands knowledge in both hardware and software systems, as well as a strong understanding of human-centered design.

E. Ethical Considerations and Standards Compliance

Throughout the development of VisionMate, ethical considerations were paramount, particularly regarding user privacy and data security. Since the system collects location data through GPS and may send emergency alerts with location information, we ensured that the system complies with best practices for data privacy and security. No sensitive data is stored on the device, and user information is only shared in case of emergency. We adhered to communication standards, particularly with the GSM module for emergency alerts, following the relevant communication protocols for secure message delivery. Moreover, we followed ethical guidelines in designing a product intended to improve the quality of life for individuals with disabilities.

F. Stakeholder Involvement

In the development of this system, we consulted with stakeholders including potential users, caregivers, and specialists in assistive technologies. Their feedback was invaluable in shaping the system's design and ensuring that it addressed the real-world needs of visually impaired individuals. For instance, users expressed the importance of having clear, intuitive feedback from the system, which led to the implementation of the haptic vibration motor for obstacle detection. Additionally, stakeholders emphasized the importance of a low-cost solution, which influenced our decision to choose affordable hardware components.

G. System Interdependence

The modules in the VisionMate system are highly interdependent. The GPS module, for example, requires the microcontroller to manage location data and provide voice navigation. Similarly, the camera module and AI processing are tied together for real-time object identification, and both rely on the microcontroller's processing capabilities. Although these modules are separate in terms of physical components, they function together seamlessly to create a unified system. The hardware modules are designed to work independently, but the software bridges them together, ensuring smooth operation across different functionalities.

P1	P2	P3	P4	P5	P6	P7
✓		✓		✓	✓	✓

TABLE I
COMPLEX ENGINEERING PROBLEM MAPPING. TICK P1 AND SOME OR MORE FROM P2-P7 AS APPLICABLE. P1 - DEPTH OF KNOWLEDGE, P2 - CONFLICTING REQUIREMENTS, P3 - DEPTH OF ANALYSIS, P4 - FAMILIARITY OF ISSUES, P5 - EXTENT OF APPLICABLE CODES, P6 - EXTENT OF STAKEHOLDERS, P7 - INTERDEPENDENCE

VI. CONCLUSION

The VisionMate project is designed to assist visually impaired individuals by providing real-time obstacle detection, GPS-based navigation assistance, environmental awareness, and emergency SOS functionalities. By integrating multiple sensors and communication modules, the system offers an efficient and user-friendly solution to enhance the independence and safety of visually impaired users.

In terms of efficiency, the system provides reliable and real-time feedback, ensuring that users receive timely alerts about obstacles, navigation, and emergencies. The response times for obstacle detection, GPS navigation, and SOS functionality are optimized to ensure smooth operation. For future improvements, the system can be enhanced by incorporating more advanced AI for better object recognition, improving battery life, and expanding communication features to support real-time remote monitoring. Additionally, integration with wearable devices like smart glasses could further enhance user experience and accessibility.

VII. ACKNOWLEDGMENT

We would like to express our sincere gratitude to our faculty Md. Shafqat Talukder Rakin for his constant guidance and support throughout the development of the VisionMate project. Every week, he took valuable updates and suggested to us how we efficiently develop the project. We are also thankful for the Raspberry Pi provided by our lab, which we were able to use only due to our faculty's recommendation. Additionally, our lab assistants were always available to assist us whenever we needed help. Their support was crucial in making this project a reality.

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